RELATIVITY

A VERY ELEMENTARY EXPOSITION

BY

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RELATIVITY

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RELATIVITY[1]

I FIND that at different times different subjects interest humanity, and the subject of special dominating interest changes from time to time. Half a century ago, or perhaps less, evolution was the word to conjure with. Now it appears to be relativity. And not only the mathematicians and physicists, but many of the philosophers, are dealing with that subject in a comprehensive manner; Lord Haldane in particular is trying to do for Einstein what Herbert Spencer did for Darwin —that is to say, to take a scientific idea, so far treated mathematically, out of the intricacies of physics, and spread it all over life, as the relativity of all knowledge.

In so doing the philosophers occasionally

[1] A Lecture to the Literary and Philosophical Society of Liverpool on October 31, 1921, reported by a stenographer from shorthand notes taken upon the evening of the address.

come to grief in their physics in a mild way, just as the physicists come to grief when they deal with philosophy. The subject is sort of betwixt and between, and it is quite easy to make it incomprehensible. Whether it is possible to make it comprehensible —well, that is what we have got to ascertain. As to relativity in general, the use of relative terms and the question of absoluteness about any of them, you know that nearly all our terms are relative. Take right and left. People tell you a shop is on the right-hand side of the street. There is no meaning in that. It depends on the way you are going along the street. But if you say right and left of the river, right bank and left bank, that has some meaning, but of course it is relative to the direction in which the river is flowing. Then there is fore and aft. That is all right with regard to a ship, but the ship may be turning round, and so it is not an absolute direction at all. It is a relative direction; it may correspond to all points of the compass.

Take east and west. That has reference to the earth. Hence you might say that to all

people on the earth it has the same meaning. In a sense it has, as when you say that Berlin is east of London and west of Petersburg. Otherwise it rather depends on where you are, when you talk about east and west, unless you are dealing with the abstract east and west. That, however, is relative to the earth, so it cannot be the same for all observers. Now, if a thing is not the same for all observers it is not absolute; it is shown thereby to be relative to something. When we can find anything that has absoluteness about it, it must be very important. Among these relative terms, it is of some interest to ask, Is there any absoluteness about any of them? Take up and down, for instance. Is there anything absolute about that? If the earth were flat up and down would have a definite meaning for everybody, and the same meaning. But it is round, and up and down has different directions for different people. Up and down in New York is at an angle with our up and down; hence evidently it depends upon the place where you are. Up and down, if you are referring to a train on a railway, is relative to

the capital city of the country. Up and down a mountain ; there is no mistake about that, but it is relative to the mountain.

There are a number of other terms I need not labour, such as far and near—it all depends on whether you have got a motor-car or whether you have to walk ; high and low, strong and weak, heavy and light, dear and cheap—all these refer to something human. Then we come to large and small. We say a planet is large and an atom is small, but what do we mean by large and small ? What is our standard of size ? Have we a standard of size ? I think our standard is the human body. Anything much bigger than the human body we call big ; anything much smaller we call small, in general. There is nothing absolute about that, and I doubt if we can imagine a limit of bigness, a limit of size. The stars are enormous, far more enormous than most people know. Their size has been measured lately. The star Betelgeux, for instance, in Orion, that red star that is beginning to rise rather late at night now at this time of the year, has had its size measured ;

and if it were put in the place of the sun the earth could revolve inside it. Its bulk would extend to the orbit of Mars, far beyond the earth's orbit. Its size is enormous, but still limited, and there does seem to be a limit of size possible to a star. Then what about the universe ? Is that infinitely big ? We simply do not know.

But putting bigness out of mind, what about smallness ? Is there a limit of smallness ? Is the atom the smallest conceivable thing ? The electron is very much smaller. When I was younger, the atom was considered the ultimate thing of which everything was built ; now it is a bulky thing comparatively. This shows how little we mean by large and small. We are accustomed in physics to think of the atom as quite large ; the electron is the small thing, as small as a flea is to this hall when compared to the atom. Well, is that the end ? Is there anything smaller than the electron not yet discovered ? Is the electron small, absolutely small, I mean in the eye of Deity, not in the human eye, of course ? We never see such things. We cannot see the atom ; it

is far too small for us to see, even with the most powerful microscope, because the waves of light are too big. We associate size with a certain complexity or possibility of complexity. We say a planet may have any number of things on it. Is such a thing as that possible to the electron, or is it too small? I do not know; I do not think anybody knows.

Then is there no absoluteness about any of these terms? Yes, strangely enough, about hot and cold. When we say a thing is hot we generally mean that we do not want to touch it. It is hotter than the human body, and when we say it is cold it is colder than the human body. Is there an absolute coldness? There is no absolute hotness. The sun is the hottest thing we know, except some of the stars, which are now believed to be thousands of times hotter. But there is an absolute coldness. We owe the determination of the absolute zero of temperature to Lord Kelvin chiefly. There is an absolute zero, the same for everybody, not only on earth but throughout the universe—one absolute zero of temperature, which is about 500 Fahrenheit degrees below

the ordinary Fahrenheit zero. It is known with some accuracy; it is known within a degree, and experimenters have got to within two or three degrees of it, by means of liquid helium. We have not quite attained the absolute zero, but we know where it is, and it was calculated long before it was got anywhere near experimentally.

Now, how can there be an absolute zero of anything? Well, just consider what heat is. It is the irregular jostling of the molecules of matter. When the molecules of matter are vibrating or moving rapidly among themselves —not all together—the body is said to be hot. Heat is that motion, nothing else. If you slow them down so that they are more sluggish, the body is cooling, getting cold. Slow them down until they stop—that is absolute zero. You cannot slow them down any more; you have got to the zero when you have taken all the heat out of the body. Of course, if you take a man's capital away he can go lower—he can get into debt; but that is not possible with heat. It gets down to zero and then stops. But you might say, "Is not the thing

moving?" Yes, it is moving as a whole—locomotion. It may be moving, but that does not matter; the common motion is not heat. Heat is the irregular jostling of the ultimate particles, and when that stops the body is absolutely cold; it is at the absolute zero of temperature. And at that temperature it has remarkable properties. It is a perfect conductor of electricity; so that if you start an electric current it goes on. There is nothing to maintain the moon's motion round the earth, but there is nothing to stop it. The same with an electric current in a body at absolute zero; it goes on because there is nothing to stop it.

Now, I come to the question of Time. Take the words "sooner or later" or "before and after" or "past and future." Is there any absolute meaning for those, or are they relative terms too? At first sight one would say that the past was past, that the future was future, and that the present was the mere slice bounding the two—an infinitely thin partition as it were between the past and the future, advancing, leaving more of the past

behind, encroaching on the future; and that we live in that slice of "present." Well, there may be animals which do live in the slice of "present," and have no memory and no anticipation. We are not in that predicament; we do look before and after. But there are certain conditions which have led relativists to hold the dogma of the relativity of time, to say there is nothing absolute about time, that the time for different observers may be different; not merely a difference like difference of longitude, but in a way dependent upon the motion of the observer. Now, here I must explain that I am not a full-blown relativist. A full-blown relativist might not agree with all I say; but I want to represent the case fairly, though the relativity of time is not an easy subject, even to those who fully believe in it.

There is a difficulty about simultaneity. When two things happen, can we tell if they happen at the same time or not? At first sight you may say, "Why, yes, I can see them happen. I know if I do something here, something else happens at the same time;

I see it." But that does not allow for the time the light has taken to come. Well then I will employ the telegraph, and if a thing happens in New York and I have it telegraphed here, say by wireless or any other method, I can tell when it happens, and can be sure that it happens at the same time as something else. But you have to allow for the telegraphic delay, which of course is very small. The time occupied is the same, or practically the same (if you have a perfect method) as that required by the velocity of light. And there is a real difficulty about determining simultaneity when you come to experiments of great accuracy. Suppose you want to determine whether the observed velocity of light depends on direction, the direction of the motion of the earth. You may send a beam of light and telegraph its arrival. The beam of light takes a certain time to go, and the telegraph takes a certain time going back; so the two going in opposite directions neutralize each other. Whether you use a beam of light to tell you of the arrival, or whether you use an electric wave, comes to the same thing; they travel

at the same rate. The reason is that they are both transmitted by the ether.

Moreover, the present moment is more than a slice. There is all that is happening at different places at about the same time, places at a distance. For instance, take the case of things happening at a great distance. In 1901 a new star burst out in the heavens, in the constellation of Perseus, I think it was. When did that happen? When you saw it? You know well that it did not happen when you saw it. It happened a good time ago, and certain circumstances connected with that star enabled people to calculate, with surprising accuracy, that it happened in the year 1603, just about three centuries before. When you saw that star you would say, "There is a new star now." Well, is it new "now"? It depends what you mean by "now." You see it now. The messenger which brought the news of the new star was light, and we know of no quicker messenger. Had it been any other messenger, such as sound, we could not have heard of it yet.

Past, Present, and Future

It is obvious and simple enough that the past controls the present; but intelligent beings are controlled also by the future. I sometimes think that that is the difference between life, especially animal life, certainly human life, and the inorganic world. The inorganic world—the atom, the matter—is pushed from behind. It is controlled entirely by the present and not by the future. But that is not the case even with an animal. A dog is controlled in his actions by his anticipation of dinner. He, too, looks before and after. He has some memory and some anticipation, just as we have more memory and more anticipation. Take for instance an eclipse. It is going to happen; it has not happened yet; you will not see it until things have had time to travel. That eclipse has caused an expedition to start now; at a certain date it started in order to see the eclipse. That is a case of anticipation. It caused the fitting out of a ship, the collecting of a number of instruments, and the travelling to a place where the eclipse

would be visible after the lapse of a certain time. In that sense the future controls the actions of the present. It is only one example of the fact that our actions are largely controlled by the future. The inorganic world is wholly controlled by the past and present. To be influenced by the future is a sign of advance.

Now, a great deal can be said about the relativity of time, but I must be satisfied with saying this: that in relativity you have to consider different ways of dividing up space and time. It might be a common mode of expression to say that the French Revolution occurred so many hundred of miles and so many years away. Distance and time can be put together. Time and distance are related. For instance, you can say truly that a kilometre is ten minutes' walk. Or, again, if you are at York, you can say that London is 200 miles away, or if you are going by train you can say it is four hours away. You very often use time as a measure of distance.

It depends on the vehicle you are thinking of. It is velocity that unifies space and time, and

you can practically use time as another dimension of space; not exactly as a dimension of space, but treated much as if it were. It is sometimes called an *imaginary dimension* of space. You see there are three dimensions of space. There is right and left, fore and aft, up and down.

Those are the three dimensions of space, and what room is there for a fourth dimension? I wish I could draw a fourth dimension on the blackboard, but I cannot. How did I get over it when I drew three? Only by a perspective dodge in which you acquiesced. I did not really draw even three. If you are to have time in the diagram as well, you must dispense with drawing one of the space dimensions. But whether you can draw it or not, you must imagine it; you must imagine progression in time. I cannot draw it, and I cannot tell you what it is doing, because it is an imaginary figure and it may be changing in time. It may be changing as an expanding circle; it may be changing even as a shrub; or as a seed which, beginning as an acorn, grows into a big tree. What is it diagrammatically doing? It

is advancing in the time dimension. Here is a thing which you will admit is the same thing, it has got an identity, just as the tree has, but it can go through all sorts of changes as it advances along the line of time, and then it can decay. Somewhat in that way the motion of planets, motion of anything, can be treated. You can speak of it as motion in a plane, or you can speak of it, if you like, as an advance in another dimension of space; and if you have already got three dimensions, as we have, in length, breadth and thickness, then time must be a fourth dimension—not accessible as a dimension, but imaginable, as if we were going through a process of development. It is development, evolution; development by travelling along the inexorable stream of time. *To us it is inexorable.* We cannot hurry it or slow it or stop it. Whether there is anything absolute about that flow of time—well, that is the question. Is it a human limitation, or is it a Divine reality?

You see we are getting into philosophy and metaphysics now. I am not trying to give you the answers to these questions, but to indicate

the kind of things meant when we talk about time being a fourth dimension, and the way in which time can be thus represented and thought of. One of the things that relativity asserts to be absolute is the completely specified interval between two events. People may differ as to how far apart they are. One will say " so much space and so much time," and another will divide up the space and time differently. Different observers, according to the theory of relativity, will split up the interval in different ways. They will say so many miles and so many seconds separate the Coronation of George V from, say, the death of Charlotte Corday. They may not agree about the miles, and they may not agree about the seconds, but they will all agree about the interval compounded of the two; which is absolute, an invariant, that is, a thing that remains constant and independent of the observer; the space-time interval is absolute. When relativity admits the interval between two events as absolute—the same for all observers, no matter how fast they are travelling, nor where they are—it has important

consequences. That is one basis of the mathematical theory.

Now, why do relativists claim that all the separate spaces and times depend upon the observer and are not absolute? To explain that, I must take another pair of terms, quick and slow. When we say a thing moves quickly—say a cannon ball moves quickly and a snail moves slowly—is there anything absolute about that? Is a cannon ball really quick? Is a snail really slow? It depends upon our estimate of space and time. Ordinary motion, as we know it, is certainly relative. You walk about on the deck of a moving ship and there is a bewildering turmoil of relativities. There is the motion of yourself relative to the ship, there is the motion of the ship relative to the earth, there is the motion of the earth relative to the sun, and there is the motion of the sun relative to the stars. At what rate are you moving? At what rate are we moving now? I know we are moving nineteen miles a second, because that is the rate at which we are going round the sun. In the time taken for a pin to drop from the

ceiling to the floor we have travelled nineteen miles. We do not look like it; it is not obvious; we think we are at rest, but we are not. We may be going very much faster, since the sun is moving too.

Is anything at rest? Motion is relative as far as we have ascertained. We do not know what rate we are moving nor where we are going. We do not know the direction nor the magnitude of our direction at this moment. We have no idea. You may say you have some idea, that you are moving with the earth, that the earth and you are moving round the sun and the sun is moving with reference to the stars. Yes, with reference to the stars; but what are the stars doing? What do you mean by the stars? You mean our visible cosmos, what we can see with a telescope, but that is not the whole. It is now thought that our system of stars, the Milky Way, our cosmos, is but one of many. Far away in the depths of space there are others, called Island Universes—other cosmoi, other Milky Ways, other systems of stars—and some of those are moving at a terrific pace, 200 miles a second.

What is our pace? We do not know. But what do you mean by moving? We can move with reference to the walls of the room or with reference to the earth, but what do you mean by moving, absolutely? What is your standard of rest?

Here is where I differ from relativists. They would say, "You have not got a standard, and to talk of absolute motion is meaningless." I would say, to talk of absolute motion with reference to nothing at all, is meaningless, but I think that we have a standard, and that that standard is the ether of space—the medium in which we are moving, the medium which extends throughout the universe, a medium which it would be absurd to suppose was in locomotion. I say that is our standard of rest for all practical purposes; and they would agree, if it exists, but as to that they differ among themselves and do not say much about it. They are quite reasonable about it, but some of their early writings make people think they have abolished the ether. Eddington does not say that, and Einstein does not. Eddington told me he had asked Einstein in

Berlin recently, who said, " No, I have no objection to the ether; my system is independent of the ether." That is all right; I agree; but that ignoration does not abolish it. When Laplace was asked by Napoleon in reference to his System of the World " Where is the Deity ? " he replied, " I have no need of that hypothesis." His system had no need. If he was always to be invoking the finger of God to regulate the planets it would indeed be a poor system! He had to explain their motions on simple mechanical principles; and *that is what he did.*

But that does not exclude the Deity from the universe. It simply means He is ignored; He is not essential for the mathematical theory. So it is with the ether. They ignore it because it is not necessary to their system, and they are quite right. If we differ, it is because they prefer to say absolute motion has no meaning, whereas I should say that absolute motion has a meaning with reference to the ether, but that we have not yet ascertained what that meaning is. In other words, we have not yet ascertained what that *motion* is.

Shall we ever be able to? Here comes the point—and this was the beginning of relativity—the proof, or shall I say the failure, the *failure to find any motion through the ether.* If you try to ascertain how quickly you are moving through ether, what do you find? Many people have tried to find it in the last half century, and they have completely failed. A great deal is known about the attempts made to measure or even detect the virtual stream of ether in which we exist. If the earth is moving through the ether it is the same as if *the ether is streaming past the earth, relatively.* You can illustrate that by reference to the air. It does not matter whether you are rushing through the air or the air rushing past you.

People have asked, "How does the earth manage to move through the ether? Does the ether stream through the earth like wind through a grove of trees?" They thought it must, but when they tried to discover the process they failed. They could not find any phenomena that depended on that. Then there was the famous experiment of Michelson, so often mentioned that I suppose you are

tired of it, but he is a great experimenter, now or recently at the University of Chicago. He was partnered in this classical experiment by Morley, and they thought they could find our motion through the ether by its effect on the velocity of light. They said, "If we are living in a stream of ether, light must go slower against the stream than with it." They devised an ingenious method for measuring the velocity of light in different directions. They had to send it to and fro. The simple thing would have been to measure the velocity first one way and then the other way, but that you cannot do because you do not know when it starts. You can send it across the stream, and simultaneously along the stream; but you must send it to and fro in either case.

Now, you can time those actions with enormous accuracy, and although there is compensation in the coming back, the compensation is not complete. I do not know whether it is obvious to you which would take the longest, to go a mile with and against a stream, or to go a mile and back across the stream, but if you do the arithmetic of it you

find it takes longer to go with and against. You are assisted with and retarded against, but the coming back takes longer and allows more time for retardation. You are not helped or hindered in going across the stream; at least, you are not hindered very much. That experiment of Michelson's apparently ought to have shown that we were living in a stream of ether, and it did not. It showed nothing. That was the beginning of the trouble. That is the experimental foundation for all this relativity. The velocity of light appeared to be the same whether going with the ether or against it, consequently it seemed to say, "There is no motion through ether at all." So some people went further and said, "You may just as well say there is no ether at all." But to say that, they could not have thought what light was, because they could not have waves of light if they did not have a vehicle or medium for them. All it really proved was that the virtual stream of ether, depending on the earth's motion through it, did not show itself.

Why did it not show itself? Was it because

the earth carries the ether with it, or carries some ether with it, so that near the earth it is stagnant? That would explain it, but then there was the experiment performed by me at the University College here in Liverpool a quarter of a century ago, when I was Professor there, which puts that out of court. I whirled steel disks at a great rate till they nearly burst, and sent light round and round between them, that way round and this way round, and compared the time taken to go round *with* the disks with the time required to go round *against* the disks; for if the ether had been carried round with the disks the beam one way would have been accelerated, and the other way retarded. There would have been a small effect. There was none. The ether was not carried round with disks. This proved that ether and matter are mechanically independent of each other, there is no friction; matter moves without the slightest resistance, and its motion does not affect the velocity of light in its neighbourhood. The possibility that the Michelson and Morley experiment could be explained by the carrying of some ether along

with the earth was clearly disproved. Was there another explanation? Here were two experiments, both undeniable; nobody controverted either of them. They seemed to be contradictory.

The explanation was suggested by my friend, Fitzgerald of Dublin. We were discussing this, and he said, "Well, I believe the thing which holds his mirrors (with which the experiment was made) shrinks when it is moving." The starting point and rebounding point of the light were on a great slab of stone. If there were a stream of ether it would be flowing through this stone. Light ought to have taken longer to go to and fro along the stream. It did not. Why? Because that stone shrank longways, and the contraction made it a shorter distance, so that that longitudinal beam is at an unfair advantage as regards the transverse beam. If the shrinkage occurred, the beam of light might take just the same time as the one that went across. We considered it, and perceived that it would do what was wanted; and soon afterwards H. A. Lorentz, of Leyden, the great Dutch

Professor of Physics, carried it a little further. He took it up, or started it independently, and showed that on the electrical theory of matter, shrinkage ought to occur, if matter was composed of electrons. It ought to occur, and, calculating the amount of shrinkage, he found that it just compensated and neutralized the Michelson-Morley experiment.

You may imagine the carefulness of the Michelson-Morley experiment when I say that the amount of shrinkage needed to counterbalance, to compensate, the retardation, is only about three inches in the whole diameter of the earth. The earth is eight thousand miles in diameter, but if it is moving along, in that one direction it is three inches shorter, and when it comes round to the other direction it gets its three inches back again. Hence a relativist will tell you that if I hold a stick so, it is one length; while if I hold it so, it is a trifle shorter. The shape and size of bodies change according to their position. A relativist would tell you so; and I am ready and willing to tell you so too.

How can I tell? If I measure it I shall not

find out, because the measure shrinks too. How do I know that though I am 6ft. 3in. if I stand up, yet if I lie down I shall change—get a bit longer or shorter, whichever it is? Do I know how much? I don't. It depends how fast we are moving through the ether. I do not know how fast we are moving. Very well, then, you do not know how long you are. We live in a queer world of ignorance, and there is no mode of testing it; so that we not only have relativity of motion, but of size and shape. A sphere is not a sphere. The effect is small, or believed to be small, because the Michelson-Morley experiment only tested the motion round the sun, not through space. We could not test that. The motion round the sun changes in six months, but the motion of the sun through space you cannot change. You can make no experiments on that; it is hopeless. You cannot measure that; therefore we do not know what size we are, or what size anything is. Everything is relative; not only time, but velocity, motion, size, shape, mass, even matter; that is a consequence of the electrical theory of matter.

A pound of matter would be rather more, if it were moving quickly, than if it were not moving quickly; so that mass is not constant, as Newton thought it was. Relativity says the same. It is consistent with relativity, but it is a sequence of the electrical theory of matter. My view is that the ether affects all these things. Motion through the ether is changing the length and size of the body, the shape of the body and its mass. Ordinarily there is no means of ascertaining these things, and hence they are all relative—nothing absolute about them. They may differ for different observers, and whether they have any absolute meaning, a relativist would say he did not know.

But is there nothing absolute about velocity? Why may man not travel through the ether at the rate of a million miles a second? Here we come across something new, something absolute! Curious! A relativist would admit it. There is a velocity—he would not call it a velocity in the ether; he might say a velocity in space; there is a velocity which you cannot exceed. If you try to move at 180,000 miles

a second the ether will just let you go; it will get out of the way, but with such reluctance that you find it extremely difficult. If you try to go 190,000 miles a second, it will not get out of the way, and you cannot go. A bullet cannot go through air quicker than the velocity of sound proper to the heated air in front of the bullet. Sound has the velocity at which air will get out of the way. When dynamite explodes, the air declines to get out of the way. The air is made to get out of the way, but then the building is made to get out of the way too. One resists as much as the other. The velocity of light is the velocity at which the ether will not get out of the way, and consequently no piece of matter can move quicker than that. That is a maximum velocity. Hence to say that the stars may after all be revolving round the earth once a day, and that we cannot be sure that the earth is rotating on its axis, is essentially absurd; not only absurd but demonstrably false.

There appears to be something absolute in the velocity of light. And this is a most remarkable conclusion of the relativist. He

would say—I would not say it, or rather I would like it to be confirmed by experiment—that whether there is a stream of ether or not, light takes the same time going with the stream as against it. Suppose you are travelling to meet the source of light, surely you will get it quicker than if you sit still, or if you run away. They say no: whether you are going faster or slower, you will get it at what seems precisely the same time.

So that there are two things absolute, the interval between two events, when you take both space and time into account, and the speed at which light moves. How does that come out of relativity? It comes out of the composition of motions. I cannot stay to explain fully how we get the composition of motions, but if you have two velocities they compound together. Supposing you are in a boat on a river; you are going, say, four miles an hour and the river is flowing three miles an hour in the same direction. What is your velocity with reference to the earth? What is your actual velocity? Your velocity is four miles relative to the river, that of the river is three

miles relative to its banks, so you get seven miles altogether. If you are going in the opposite direction you get one mile. Is not that common sense? If you have two velocities u and v you compound them into $u + v$, but when you apply the relativist doctrine, mathematically, taking into account all that I have tried to sort of skim the cream off, that is not the law of composition. The resultant velocity is not that, but

$$u + v \text{ divided by } 1 + \frac{u\,v}{c^2}$$

where c is the velocity of light. This unexpected denominator is 1 + the product by the square of the velocity of light. That fraction of $u + v$ gives w, the resultant velocity. That denominator is introduced by the theory of relativity, it is introduced by the Fitzgerald contraction, by all the different things I have been explaining, and I admit it is there. It is a very curious thing, it is a very odd formula for the velocity. If the velocity c were infinite, the whole thing would be common sense again —the resultant velocity would be $u + v$

simply—but as the velocity of light is not infinite, there is a very small correction which has to be applied; which, strangely enough, has to be applied in actual practice when things are moving quickly enough. Some of the planets are moving quickly enough. Mercury is moving quickly enough, and it affects the motion of Mercury slightly.

Now go further and suppose that I am compounding something with the velocity of light itself; instead of only the motion of the earth relative to the sun, and the sun relative to the stars, or instead of any other two motions that you can think of which you might take as u and v. Take my experiment with the revolving disks. I was trying to modify the velocity of light by compounding that velocity with another one, that of the disks, or the velocity of the ether between the disks. I was looking for a velocity $c + v$, trying to compound c with another velocity v, somewhat as in the Michelson and Morley experiment. I was sending light down the stream and up the stream, aiming at $c + v$ and $c - v$; trying, in fact, to see if the velocity of light increased

up stream and diminished down stream. Neither they nor I found anything. Why not? Because that is not what could have been found. Look at this equation. It expresses the new law for compounding velocities, and algebraically the result is c.

$$w = \frac{c + v}{1 + \frac{cv}{c^2}} = c.$$

They did not know it, I did not know it, but that is the law of composition according to this formula, when one of the velocities is c and not u. Work that out algebraically. Give it to your boy and he will tell you the result is algebraically c. It comes out the velocity of light and nothing else. You have tried to increase the velocity of light by adding v to it, but you cannot. It is unchangeable. Hence, the experiments were all bound to give negative results, without any talk about the ether, without any talk even about the Fitzgerald shrinkage, because of that law of composition which is the law appropriate to relativity, and its curious treatment of time.

I am coming to the end of my programme, though I have still got to introduce gravitation. When we introduce gravitation all manner of other things happen. You begin to doubt Euclid, and to talk about the nature of space; relativity is supposed to do away with gravitation. When you come to look into the matter, as to what you really observe, instead of only what you think you observe, you find a difficulty. You think you observe an attraction of one body for another. The earth attracts the moon. How can it attract the moon when it is not there? There is a great distance between the bodies. How can any body act directly at a distance? Newton knew it could not, but he did not know enough to explain how it happened. He could surmise, as we can and do, that both the earth and moon act on ether, and that the ether presses them together. But statements like that are of no value until they are worked out. We can safely say that the moon moves exactly as if the earth attracted it, but the apparent attraction has still to be explained.

Einstein's is an attempt to work it out,

using different language. He would say: Here is a particle moving by itself in empty space. Here I put in its path not exactly an obstruction but a curvature, a pucker. Let the particle be moving in a sheet like a stretched plane, and let us make somewhere in that plane a pucker, and let the particle have to go near that pucker, which we will call a mountain. Suppose you want to go the easiest way, you won't go like the land crabs or some animals do, straight up the mountain or the house or whatever the obstruction is —up and over and down. You will prefer your path diverted, you will try and go round it. Your path will become curved, to get as little of the pucker as possible. You will stretch the apparent length of your path to get an easier, shorter-time path. Your path will be curved with reference to this pucker. But you might also express the motion by saying that the moving thing is apparently attracted by the pucker and so curved round. It is something like the hyperbolic orbit of a comet attracted by the sun. Space seems warped.

What is that warp? A warp in space has caused the path of a body to be curved in order to get the line of least resistance. No longer would you call it an attracting force. You would simply say that the path is the effect of a warp in space. What is the warp due to? You might say, to an atom or mass of matter at its centre. You might claim that matter warps the space all around it, and accordingly that the gravitational behaviour of bodies is as it is. We live in a warped space.

Now, is it right to say that matter causes the warp, or that the warp is matter? A full-blown relativist would say that that is what you mean by matter. These warps rise in the centre not only to a pucker that can be got round, but to one that *must* be got round; so that if you try and go through the centre you are up against the impenetrable. You cannot get through the centre.

The impenetrability of matter follows, therefore, as well as the attraction of matter. I do not suppose I have made that clear at all, but still I have indicated roughly the kind of way in which these warps in space simulate

and replace the effect of gravitation. Only to me a warp in empty space is meaningless. An effect on the ether is full of meaning, and I believe the sun and all the planets do really affect the ether in such a way as to produce their actual paths, which we may likewise attribute to a pressure on them all towards the sun. You may as well call it a warp as anything else; and by calling it a warp you can, for the time, avoid the necessity not only of gravitation but of matter itself. Everything then becomes reduced to geometry, and Euclid's propositions are not strictly true. In the warped space or ether you have a different kind of geometry.

Now, strangely enough, the geometricians of the past had invented a hypergeometry that was not Euclid's, and that seemed to have nothing to do with anything but imaginary and ideal laws. Einstein had the genius to perceive that this hypergeometry would do what he wanted in the physical real world. By using that geometry he could work out the whole of the universe, so to speak, on geometrical lines; dispensing with physics, force,

matter—with any of those things that we have lived on—and reducing it all to pure mathematics. It was a *tour de force*. It is a wonderful achievement, very brilliant, and I do not wonder mathematicians are enamoured of it. But the end is not yet, and we shall come out into common sense later on, with the addition of those great and notable discoveries which have followed from this method of treatment. For, mathematically considered, relativity is a splendid instrument of investigation, a curiously blindfold but powerful *method* of attaining results without really understanding them. There have been several of such methods—second law of Thermodynamics and others—but they ultimately have to be explained by physics. They are not a substitute for physics, they are not a philosophy. If pressed unduly you can manage to express things rather absurdly, but the method is a way of arriving at real results and of dealing with abstruse and hidden problems. Relativity is not a replacement but a supplement of Newton.

Lastly, consider for a moment the relativity

of human knowledge. Eddington says, towards the end of his book, *Space, Time, and Gravitation* :

> The theory of Relativity has passed in review the whole subject of physics. It has unified the great laws which by their position hold a proud place in knowledge, and yet this by itself is only an empty shell. The reality is in our own consciousness. There are mental aspects deep within the world of physics.' We have only regained from nature what man has put into nature. Everything is relative to human perception.

This may be understood, or misunderstood, as meaning that there is no objective reality at all, that things are as it were brought into existence by our conceptions of them, that a subjective existence is all the existence they have. Any such interpretation as that I repudiate. Our perceptions enable us to disinter from nature some part of what is already there—and which we certainly did not put there—but the phenomenal aspect which reality assumes to us, in other words its appearance, does depend on our modes or channels of perception and on our interpretative human mind. Objective reality exists,

but it is we who interpret it. The universe is incapable of being completely comprehended by any finite being, it must be interpreted; and the way we interpret it depends on ourselves and on our faculties. Absolute reality might presumably be apprehended and formulated and perceived in a great number of different ways; we apprehend it in a human way, and our science must be conditioned by the human mind; it is therefore bound to be relative to the human mind. But the human mind is not a constructor of nature—only an interpreter. Objective reality exists, and makes an impression on us. The impression it produces depends on what we bring to its perception. Surely it is the same not only in Science but in Art. An artist perceives, or in a sense discovers, and displays his vision of reality to those who have senses to appreciate—not senses only but an adequate mind too. For example, a man perceives one aspect of a work of art, an animal perceives another—in so far as it perceives it at all. In that sense, and in that sense only, we get from nature what we put into it. We do not doubt that

man sees it more truly than the animal. How God perceives it, or what it is in ultimate reality, we do not know. Our interpretation is relative to our own consciousness, even to our own individual consciousness; but there are levels of consciousness, and science seeks to raise our conceptions above what is merely individual, and aims at universal truth—truth acceptable to all humanity.

And so, concerning all the discoveries which have been flooding in on us of late about the Universe, humanity can say, as Eddington eloquently says at the end of his remarkable book:—

> We have found a strange footprint on the shores of the unknown. We have devised profound theories to account for its origin. At length we have constructed the creature that made the footprint, and lo, the footprint is our own.

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